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Noise Reduction and Communications in the CC 130 Hercules Aircraft

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Abstract

The purpose of this project was to study ways of creating a better acoustical environment for the crew of the Search and Rescue (SAR) CC 130 Hercules aircraft. The ultimate goals were to improve communications and reduce noise dosage, thus preserving hearing. Several commercial products were tested to assess their effectiveness in accomplishing the two outlined goals. The products included various Active Noise Reduction (ANR) Headsets, the Communications Ear Plug (CEP), and the standard issue Communications Headset. The Microphone In Real Ear technique was used in real human subjects to assess the amount of attenuation provided by each headset when exposed to 97 dB of mauve noise. A Kunov Mannequin, a binaural acoustic test fixture, was used to assess the amount of attenuation offered by the CEP in the same environment. Real human subjects were also subjected to the Modified Rhyme test in combination with the Maximum Likelihood Procedure to determine the signal to noise ratio required for each communications device to achieve a level of 60% speech intelligibility.

Out of all the communications devices tested, the Sennheiser HMEC 222 and the CEP, worn in combination with the David Clark H10-76 provided the greatest amounts of noise attenuation. In terms of speech intelligibility, the Sennheiser HMEC 222 achieved the lowest signal to noise ratios in both the active and passive modes. The CEP worn in combination with the David Clark H10-76 provided the second lowest signal to noise ratio.

Based on performance in this study, the Sennheiser HMEC 222 is being recommended as the most effective communications product for the Hercules environment. Competitive results were seen from the CEP which is a much more cost effective device. Therefore, SAR crews should have the opportunity to try both of these products during flight to assess issues of usability and comfort.

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Introduction

The Defence and Civil Institute of Environmental Medicine (DCIEM) is a human factors centre under the Department of National Defence. It was designed to solve human factors problems that occur within the military. There are many divisions within DCIEM; this project was completed by the Communications Group, which is part of the Human Factors of Command System Section. The mission of this group is to assess noise exposure levels in various military environments and offer possible solutions to preserve and protect the hearing of the soldier, pilot or employee.

This project was completed under the New Search and Rescue Initiatives Fund (NIF). The NIF was established by the National Search and Rescue Secretariat (NSS) to provide funding for projects aimed to enhance Search and Rescue (SAR) in Canada. The fund was developed with six priority areas. The aim of this project was to answer a portion of the priority requesting "timely Research and Development products that allow the Canadian SAR system to meet the challenges of the next century particularly in the areas of communications, technology for better searching, search theory and practice and resource management" (NSS, 1998).

More specifically this project was completed for the Search and Rescue (SAR) crew of the CC 130 Hercules fixed wing aircraft. Please refer to Appendix A, figure A1 for a photo of the Hercules. The high noise levels and long duration flights have resulted in permanent hearing damage for many of the Hercules crew. Communication is difficult in such an environment, but essential for effective operation of the team. The volume of the intercommunications system (ICS) plays a large role in the level of noise exposure experienced by the crew. During the flight trial for this study, crew members were asked to unplug from the ICS, one at a time, so that the at-ear noise level could be measured without the noise of the ICS traffic. At-ear noise levels were also recorded when the crew members were plugged into the ICS. Differences up to 9 dB were seen when comparing the at-ear noise levels for ICS on and ICS off for both the flight engineer and load master. Please see Appendix B, table B-1 for tables of these at-ear noise levels. The volume of the ICS necessary for effective intelligibility will be reduced by finding a communications device that permits lower at-ear noise levels and clear speech transmission.

In order to make valid comparisons and recommendations regarding the most appropriate communications device for use in the Hercules aircraft, there are a number of measures that need to be made. Each device will undergo a frequency response to pink noise, a physical measure revealing the capacity of the transducer to transmit noise of all frequencies. An ideal response is a flat line right across the spectrum as pink noise consists of equal energy per octave band. Experimental measures, those using real human subjects, include determining attenuation capabilities of each communications device in mauve noise and a speech intelligibility test for each device. The Modified Rhyme Test

(MRT) is a standard speech intelligibility test that was paired with the Maximum Likelihood Procedure (MLP) to achieve a speech intelligibility of 60%. Subjects were also asked to answer a questionnaire after wearing each headset. This provided subjective feedback on issues such as comfort, effectiveness of the ANR and overall function of each headset.

The purpose of this project was to study ways of reducing the noise dosage for the crew while at the same time improving the effectiveness of speech intelligibility. A number of state of the art communications devices were examined in this study and compared in noise attenuation and effective speech transmission. The devices included four Active Noise Reduction (ANR) headsets: the Bose Aviation II, the Bose AHX, the Sennheiser HMEC 222 and the David Clark H10-13X. Also studied was the Communications Ear Plug (CEP) worn in combination with the standard issue headset and the standard issue headset, the David Clark H10-76, worn alone. Please see Appendix A, figure A2 for a photo of these headsets.

Active Noise Reduction is an electronic technique that picks up the ambient noise heard within the ear cup and then emits the same sound pattern in the opposite phase. This creates destructive interference with the ambient noise in the ear cup and works to reduce the noise. ANR is most effective in reducing low frequency noise (Crabtree, 1996). The importance of eliminating low frequency noise cannot be overlooked because of a phenomenon called forward masking. Forward masking occurs when the transmission of low frequency noise interferes with, or blocks the clear transmission of higher frequency sounds (Crabtree, 2000). Since speech is in the mid range, about 300 to 3000 Hz and the Hercules noise contains large amounts of low frequency (up to 107.5 dB at 63 Hz), forward masking is a serious concern in this environment. Passive attenuation works best on higher frequencies. Even a strong passive attenuator will not have large effects on low frequency noise, leaving speech range frequencies vulnerable to forward masking. Ultimately, forward masking causes a decrease in speech clarity and results in higher required volumes for acceptable intelligibility.

The Communications Ear Plug (CEP) consists of a foam ear plug with a transducer embedded through its centre. The foam ear plug works to attenuate background noise, thus protecting the hearing of the user, while the transducer transmits the signal from the ICS of the aircraft directly into the ear. The foam plugs come in a number of sizes allowing a more personalized fit. They are also detachable from the earphone so the plugs can be cleaned and replaced as necessary. All sizes of the foam plugs are designed to house the same transducer. The signal lead of the transducer extends radially from the plug to fit nicely within the confines of a standard circumaural ear cup. See Appendix A, figure A3-A4 for photos of the CEP.

Methods

Flight Trial

On January 23, 2001, a team from the DCIEM Communications Group visited the Canadian Forces Base in Trenton Ontario to fly with the SAR crew on the CC 130 Hercules. The purpose of the flight was to make high quality digital audio recordings of the ambient noise in the aircraft and the at-ear noise experienced by the crew-members. Sound pressure levels were also taken via sound level meter. The objective of the flight trial was to record data that could be used to simulate the Hercules noise as realistically as possible in the Noise Simulation Facility at DCIEM. Two flight conditions were chosen, search (1500 feet, 150 knots) and transit (1500 feet, 250 knots) as both are common in SAR missions and both are known to be noisy. Recordings and measurements were made during both conditions.

An AKG Acoustics model C414-ULS microphone was flexibly suspended centrally in the cockpit just above the flight engineer. Another was placed above the starboard side of the table in the fuselage, at the forward end of the cargo area. These microphones captured the ambient noise and sent it to respective digital audio recorders.

Sound pressure levels were measured in 1/3 octave bands from 12.5 to 20 000 Hz and stored using a Quest Model 1900 Sound Level Meter. See figure 1. These levels were measured at various locations throughout the plane: just lateral to the ear of the pilot, co-pilot, navigator, flight engineer, in a stationary aft position for the load master, in the port and starboard SAR chairs and at the starboard side of the table in the cargo area.

The co-pilot, flight engineer and load master were fitted with tiny ear microphones that wrap around the pinna to hang in the opening of the ear canal, before flight. Please refer to figure 2 for a photo of the ear microphones and the wiring used to connect them to the digital audio recorders. The ear microphones were fed back to digital audio recorders, to record the at-ear noise levels for each of these positions. Choosing these crew-members to wear the ear microphones provided at-ear noise levels for two central flight deck positions as well a position located in the cargo area. Crew-members were asked to unplug from the ICS for a short period of time so that at-ear noise levels could be compared with and without the added sound levels of the ICS traffic and the amount of noise created by the ICS traffic could be determined. Please see Appendix B, table B-1 for these values.

Figure 1: A DCIEM Communications Researcher measures the sound levels in 1/3 octave bands, using a Quest Model 1900 Sound Level Meter, just lateral to the left ear of the Navigator in the cockpit of the CC 130 Hercules.

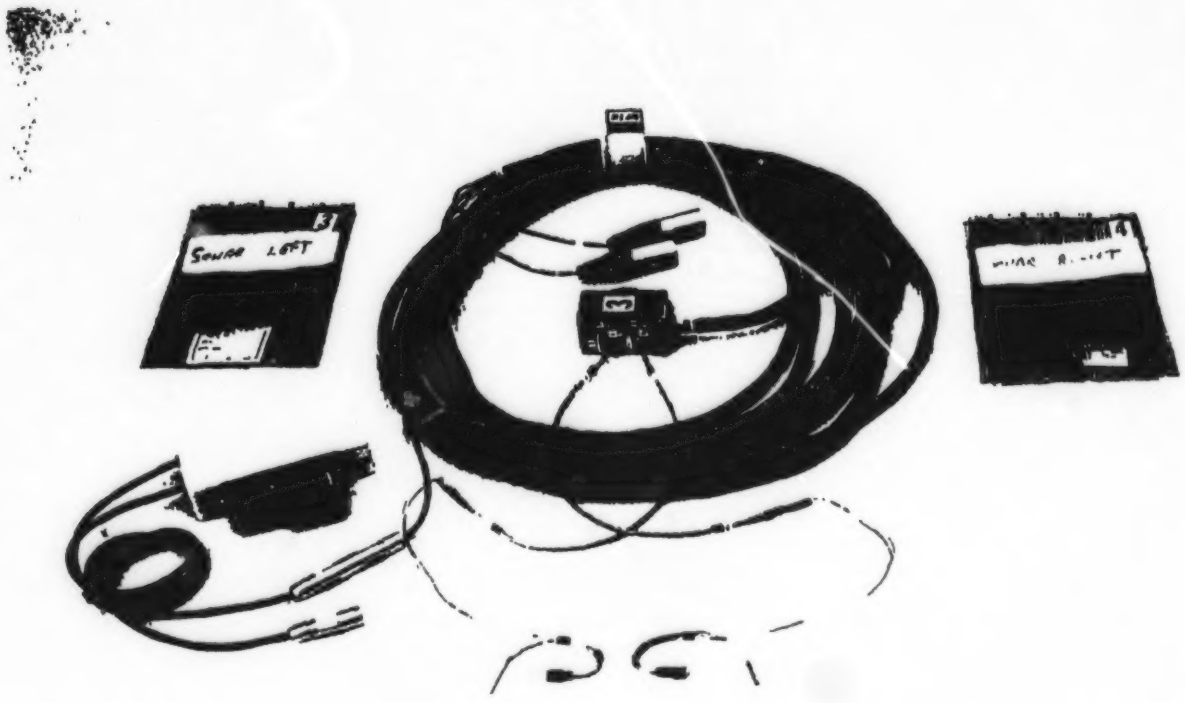

Figure 2: Displays the ear microphones used in the MIRE technique, their power source, the wiring used to connect them to the digital audio recorder and the envelopes used to organize and store the microphones when they are not in use.

Experimental Preparation

In the lab at DCIEM, the sound spectra stored by the Quest Model 1900 Sound Level Meter were graphed and studied. The Hercules noise contains especially high sound pressure levels in the low frequency ranges of 16 and 63 Hz. Please see figure 3 for the sound spectra recorded for the flight engineer in the transit flight condition. This figure provides a typical example of the Hercules sound spectra; although levels vary in different positions in the aircraft, the general shape of the sound remained the same. This is the spectrum that was used to model the shape of the simulated Hercules noise in the lab at DCIEM. It was chosen for a number of reasons. The flight engineer occupies a central position on the flight deck, and this spectrum gives a good representation of all positions. Also, the flight engineer was seated directly below the ambient microphone, therefore this spectrum matches most closely with the noise recorded by the digital audio recorder. Finally, the transit flight condition was chosen because sound levels were higher than in the search condition.

A three-minute sample of the digital audio recording made by the ambient microphone in the cockpit, chosen for a smoothness of sound with no incidental noise or conversation, was looped into a two-hour continuous recording to be used in the laboratory study. An audio software editing program called Cubase VST (Virtual Studio Technology) was used to create the loop without any thumping or clicking at the splice.

The following measures were taken in order to correct for any distortions or reverberations in the noise that may be caused by the size and shape of the lab. The two hour Hercules noise tape was played into the noise lab where a Brüel and Kjær (B&K) half inch free field measurement microphone model 4149 was set up at seated head level in the exact spot that subjects were seated for the study. The microphone fed the sound to a B&K digital signal analyzer model 2133 that displayed the sound spectrum in 1/3 octave bands in real time. The desired Hercules sound spectrum, as recorded during flight, was also entered and displayed on the analyzer. A Yamaha Digital Equalizer model DEQ7 was used to shape the noise in the lab into the spectrum that was recorded on during flight. Four filters were used to accomplish this task. The widths of these filters and their locations on the spectrum were recorded in the DEQ7 to be used every time the tape was played.

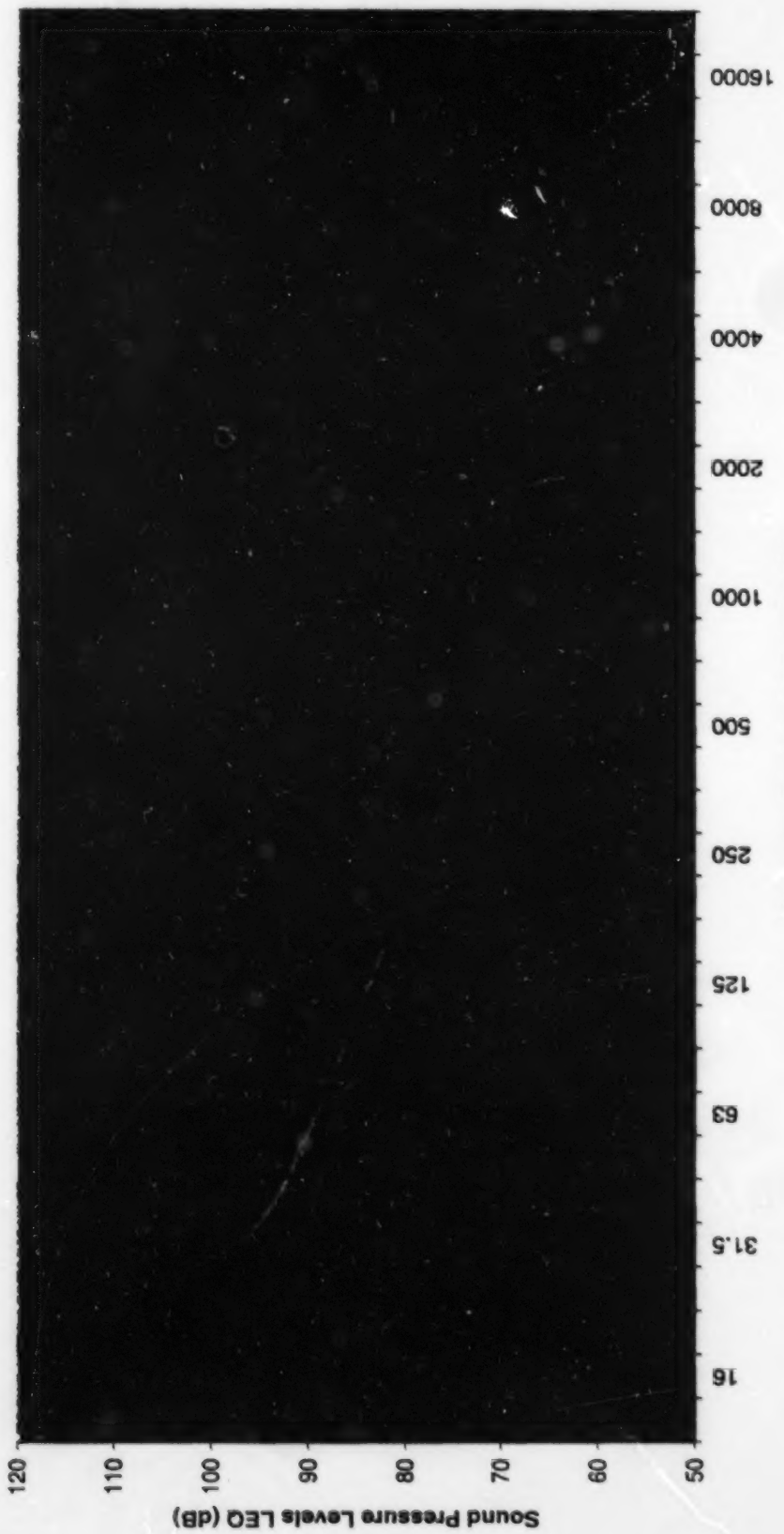

Figure 3: The Sound Spectrum Measured in the position of the Flight Engineer during Flight Condition One: Transit (1500 feet, 250 knots)

Laboratory Study

For direct comparison of Modified Rhyme Test (MRT) results between headsets, the MRT must commence at the same level in all cases. Therefore, the carrier phrase must be presented at the same signal-to-noise ratio (SNR) in each headset under each condition. Conditions include ANR on and off as well as the male versus the female speaker. However, the headsets vary in a number of ways that affect the SNR: passive attenuation, active attenuation, and sensitivity of the transducer. Each of these variables must be measured and accounted for in order to ensure equivalent signal-to-noise ratios and thus comparable MRT results.

Pilot studies accounted for many of these variables. The Microphone In Real Ear (MIRE) technique was used to measure at-ear noise levels of the four Active Noise Reduction headsets and the standard David Clark Communications headset in simulated Hercules noise. Four subjects used each headset twice in each condition. The results were averaged to give a reasonable estimate of the at-ear noise level for each headset in each condition in Hercules noise. Please see Appendix C for tables of these values.

A flat plate coupler was used to measure the at-ear level of the signal sent through the transducer of each headset. The flat plate coupler provides a perfect seal to the ear cup of each headset, thus eliminating as much noise as possible, allowing a measure of the signal (speech) alone. The carrier phrase "next word" was repeatedly sent through the ICS connection of each headset and the peak dBA level was measured and recorded for both the male and female speakers. This provided a measure of the signal level for each headset in each condition. Using a volume control, the signal level for each headset was raised to be approximately 5 dB higher than the corresponding at-ear noise levels measured in the pilot study. The position of the volume dial was noted and marked. The peak dBA levels for each condition of the headset were measured and recorded at this volume setting. The computer program that runs the MRT has a built in feature allowing individual attenuation of each signal under each condition for each headset. The difference between these new signal levels and the noise level heard at the ear was programmed as the amount of attenuation required for each specific condition, providing a SNR of 0 dB, that is, the signal and the noise have the same level. Under these conditions, the carrier phrase is clearly audible within the noise. The reason for this technique of raising the signal and then attenuating via the computer is to achieve the same SNR at the same level on the volume control for all conditions within a headset. It also provides some leeway to adjust the signal during subjective testing.

The Communications Ear Plug (CEP) required different measures since neither the MIRE nor the flat plate coupler can be applied to the CEP. Measures with the CEP were taken with the aid of a Kunov Mannequin, a binaural acoustic test fixture. Please refer to figure 4. The first measurement taken with the mannequin was an open ear measurement in

in simulated Hercules noise. Next, the CEP was inserted into the soft ear canal and the standard David Clark H10-76 was placed on the mannequin as in a normal fitting. A headband was secured around the headset, ensuring a tight seal. A waiting time of approximately five minutes was allowed to ensure full expansion of the foam tips of the CEP in the cold ear canal of the mannequin. The carrier phrase was then sent through the transducer of the CEP and peak dBA levels were measured and recorded for both male and female speakers. This provided the signal level for the CEP. The same procedure was then followed for the CEP as was used with the headsets. The volume control was adjusted to raise the signal approximately 5 dB higher than the highest signal and the computer was programmed to attenuate each signal to be equal to the at-ear noise level, thus providing a SNR of one to one.

The next step in preparing for an effective MRT was a subjective confirmation of each condition for each headset. The carrier phrases, male and female, were played with the appropriate attenuation levels for each condition in Hercules noise. Listening to the levels acted as a double check to ensure the previous calculations were perceived as being correct. It also provided subjective feedback and the attenuation levels of five specific conditions were changed. The new levels and therefore new signal to noise ratios were recorded. For starting signal to noise ratios please see Appendix B, table B-2.

Using the same equipment, the flat plate coupler for the headsets and the mannequin for the CEP, pink noise was sent through each device. The noise was generated at a level specific to each condition that produced an A-weighted equivalent of approximately 80 dB for that condition; the exception being the David Clark H10-13X headset. Volume control problems allowed the generation of pink noise through this headset to reach only 50 dBA, which explains why this line appears several dB lower than the others in figures 6 and 7. These problems were solved before continuing with the study. Please refer to figures 6 and 7 in the findings section of this report for the resulting frequency responses for each of the six devices in the passive and active, ANR off and on, conditions.

The next part of the experiment involved real human subjects, both male and female between the ages 20 and 30. All subjects were given a hearing test just prior to the study, only those with no loss greater than 20 dB at any frequency between 125 and 10 000 Hz were selected to continue. Subjects were fitted with classic E.A.R. yellow foam ear plugs and ear microphones to use the MIRE technique. Subjects were then exposed, one at a time, to approximately 97 dB of mauve noise. Mauve noise is a combination of white and pink noise, consisting of pink noise below 1000 Hz and white noise above 1000 Hz. It was developed at DCIEM specifically to be used in attenuation studies. While subjects were in the mauve noise, measurements were recorded for each condition, ANR on or off, for each headset. Each headset was fit three times and the same measures were taken with each fit. An open ear measurement was also recorded. This was accomplished safely as

Figure 4: A DCIEM Communications Researcher inserts the CEP into the Kunov Mannequin for testing in the Noise Simulation Facility.

the EAR plug sits inside the ear canal and therefore can be worn at the same time as an ear microphone. Thus the subjects were never exposed directly to the 97 dB mauve noise. The amount of attenuation for each specific condition was determined by subtracting the at-ear noise levels for each headset in each condition from the at-ear noise levels of the open ear measure. Results were averaged between left and right ears, between the 3 headset fits and also between subjects, providing a total n of 42. Direct comparisons of the attenuation capabilities of each communications device under each condition can be seen in figures 8 and 9 in the findings section of this report.

The final step in the experimental protocol was the Modified Rhyme Test (MRT). The MRT was combined with the Maximum Likelihood Procedure (MLP) through a computer program to allow a final outcome close to 60 % speech intelligibility over each trial. Each trial consisted of the presentation of 50 words heard through the intercom system of the selected communications device. Ear microphones were worn under each device to measure the noise level at the ear. The noise level measured with the CEP represents that in the ear cup, and does not include any attenuation provided by the CEP. Subjects were seated in front of a computer screen that displays a matrix of six phonetically similar words. Please see figure 5 for the experimental set-up. The subject had to choose the presented word, heard through the communications device, from the six words displayed in the matrix and respond on a small keyboard containing six buttons set up in the same matrix as the words on the screen. Thus each button corresponded to a single word in the matrix. The level of the presented word was varied according to the MLP and the answering history, in an attempt to reach the level where the subject would achieve a correct response rate of 60%. If, on the 50th word, the correct response rate for the presented level was not exactly 60%, the computer used a predetermined psychophysical sigmoidal shaped curve to estimate the sound level that would yield a correct response rate of 60%. Four trials were performed by each subject for each condition: two with the male speaker and two with the female speaker. Subjects were not permitted to remove the headset until all conditions for that headset were complete. This ensured comparable results within each headset as all MRT trials were performed with the same fit.

Upon completion of all MRT trials for a given headset, subjects were requested to fill out a questionnaire. One questionnaire, the ANR questionnaire, was given for all four ANR headsets and a separate questionnaire, the Communications questionnaire, was given for the CEP worn in combination with the David Clark H10-76 and the David Clark H10-76 worn alone. Having two questionnaires allowed questions to be asked specifically about the active noise reduction for the four ANR headsets. Many of the questions are the same on both surveys, allowing comparisons across all devices. Please see Appendix D for a copy of the questionnaires.

Figure 5: A DCIEM Communications Researcher places the David Clark H10-76 on a subject in the Noise Simulation Facility in preparation for an MRT trial. The subject is wearing ear microphones and the CEP. The subject is seated in front of a computer screen where the six-word matrix of the MRT will be displayed. The same set-up was used for each of the six communications devices.

Findings

Frequency Response

Results for the frequency response to pink noise were comparable across all headsets when ANR was off. The two flattest lines were seen in the David Clark H10-76 and the Bose AHX-04. The Bose Aviation II has a large peak right in the mid-frequency range while the Sennheiser HMEC 222 displays a gradual climb in sound pressure level until about 500 Hz where it turns to descend until it reaches about 2000 Hz. All headsets, whether ANR was on or off, resulted in large peaks and valleys in their response at frequencies greater than 2000 Hz. The David Clark H10-13X appears at a lower sound pressure level, due to the volume control problems mentioned earlier in this report. Although the response of this headset is variable, the slope of the overall response is quite flat. Smooth gradual changes in a sound spectrum result in more natural sound quality than abrupt changes in sensitivity. Peaks and valleys such as those produced by the David Clark H10-13X alter the way a voice sounds, making it more difficult to understand. Please refer to figure 6.

When the ANR was switched on, the frequency response for the Bose Aviation II became remarkably flat. The CEP, worn by the mannequin in combination with the David Clark H10-76, also responded to the pink noise with a very flat line. The Bose AHX-04 and the Sennheiser HMEC 222 responded with very similar curves as displayed in the ANR off condition, however, in both cases, the curves became more exaggerated when the ANR was turned on. Finally, the David Clark H10-13X responded with similar changes as seen in the ANR off condition but the overall slope was in a greater decline. Please refer to figure 7.

Attenuation

Results for the attenuation of 97 dB of mauve noise were very consistent across all headsets in the ANR off condition. The shape of each line was very similar with the maximum and minimum values for attenuation at any frequency point of the graph differing by no more than 11 dB. However, the Sennheiser HMEC 222 and the David Clark H10-13X had the largest integrated area and thus provide the greatest passive attenuation. The Bose AHX-04 and the Bose Aviation II both fell slightly below the zero line at low frequencies, thus indicating that at-ear noise levels were actually slightly higher than those in the room, outside the ear cup. Both Bose headsets displayed similar curves and provided similar amounts of passive attenuation. The David Clark H10-76 provided comparable amounts of passive attenuation at low frequencies to the Sennheiser HMEC 222 and the David Clark H10-13X. It did not perform as well at high frequencies, falling about 10 dB below the leading headsets. Its overall passive attenuation placed it in the middle of the field. Please refer to figure 8.

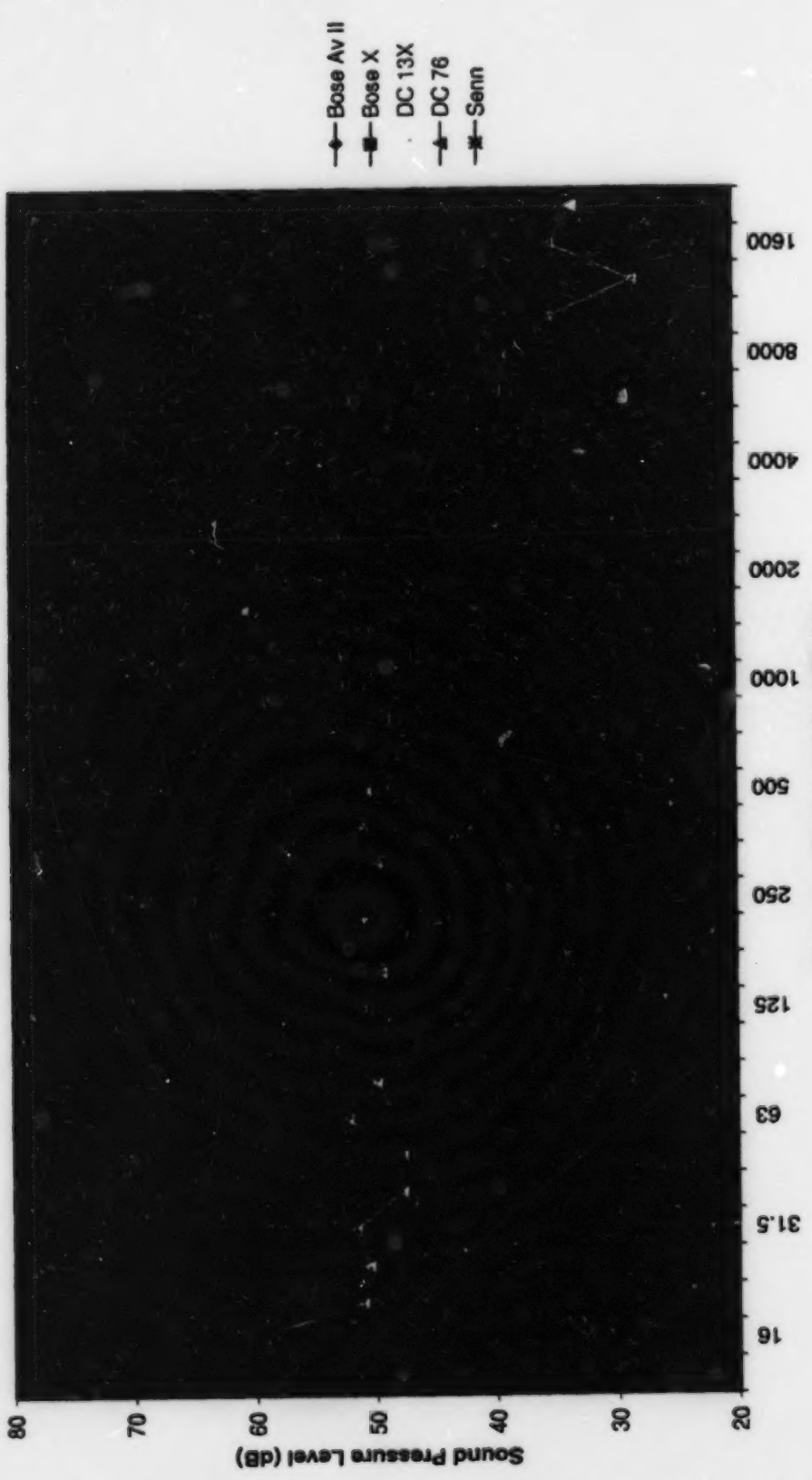

Figure 6: Frequency Response to 80dB of Pink Noise, ANR OFF

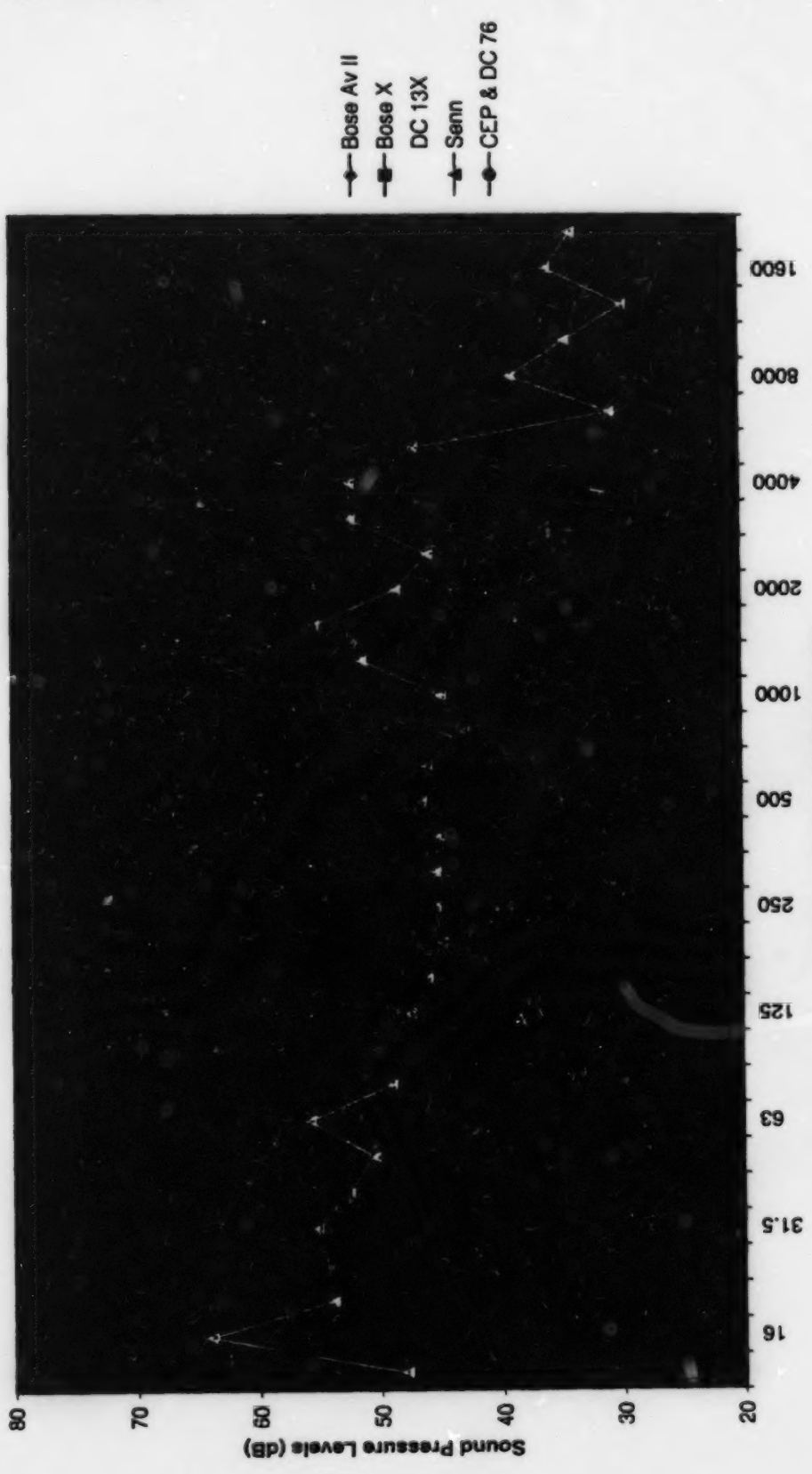

Figure 7: Frequency Response to 80dB of Pink Noise, ANR ON

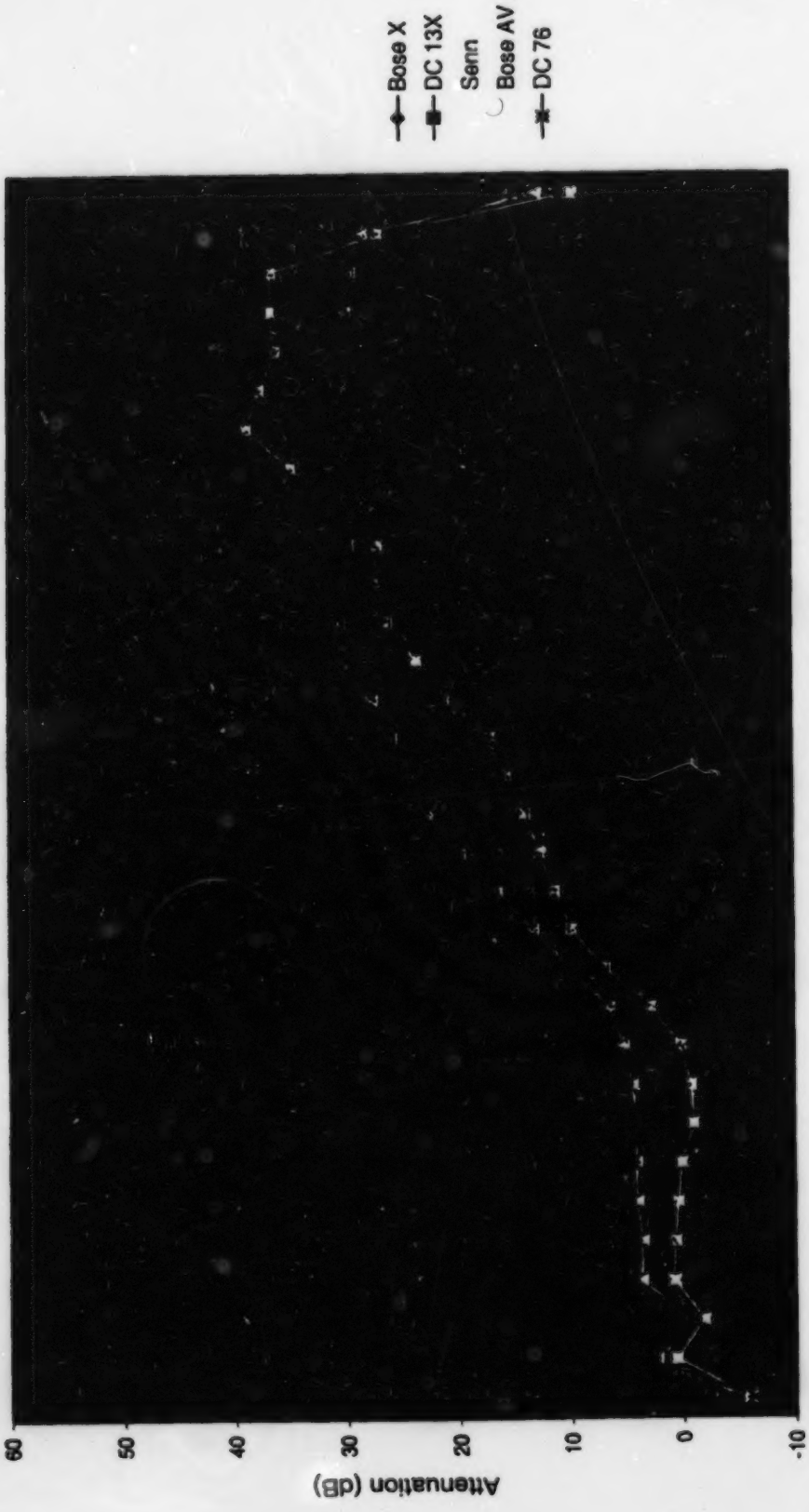

Figure 8: Attenuation of each Headset in 97dB Mauve Noise, ANR OFF (average of all subjects)

There was a dramatic change in the amount of attenuation seen in all headsets when the ANR was switched on in 97 dB of mauve noise. Please see figure 9. The integrated attenuation increased in all cases. Both Bose headsets moved above the zero line at low frequencies, with the Bose AHX-04 providing up to 10 dB of attenuation at frequencies that were below the zero line in the passive, ANR off, mode. All curves showed substantial increases in attenuation at frequencies below 500 Hz, but had similar attenuation levels at frequencies above 1000 Hz. The CEP worn by the mannequin in combination with the David Clark H10-76 provided competitive amounts of attenuation at low frequencies, and appears to offer up to 20 dB more protection in the high frequency range. The shape of the curve and the levels of the spectrum are comparable with those found in Erika Hasler's study on tandem protection (DCIEM, 2000). However, attenuation was calculated by subtracting the at-ear noise levels found under the communications device from the at-ear noise levels of the open ear condition. Due to ear canal resonance, the at-ear spectrum measured in the mannequin contains levels much higher than those recorded by the ear microphones worn by the human subjects. Furthermore, inserting the CEP changes the canal from an open-end pipe to a closed-end pipe and therefore also changes the resonance. The mannequin also affords a perfect fit for the CEP and a perfect seal for the David Clark H10-76, which inflates the amount of attenuation in comparison to what would be seen in a real human subject. Therefore, the CEP has a different starting point, and a more ideal test method than the other communications devices when determining the amount of attenuation it provides. Moreover, the levels of attenuation calculated for the CEP, worn by the mannequin in combination with the David Clark H10-76, surpass the subjective limit of attenuation imposed by bone conduction in humans. This limit suggests that maximal attenuation for frequencies of 6300 Hz and above is about 50 dB (Berger, 1984). The attenuation levels achieved in this frequency range when using the mannequin were up to 60 dB. Levels that are impossible to reach in human subjects due to bone conduction. Thus, it is difficult to compare the CEP with the headsets. Future studies should investigate attenuation in the same six communications devices using the same procedure but use the mannequin for all devices.

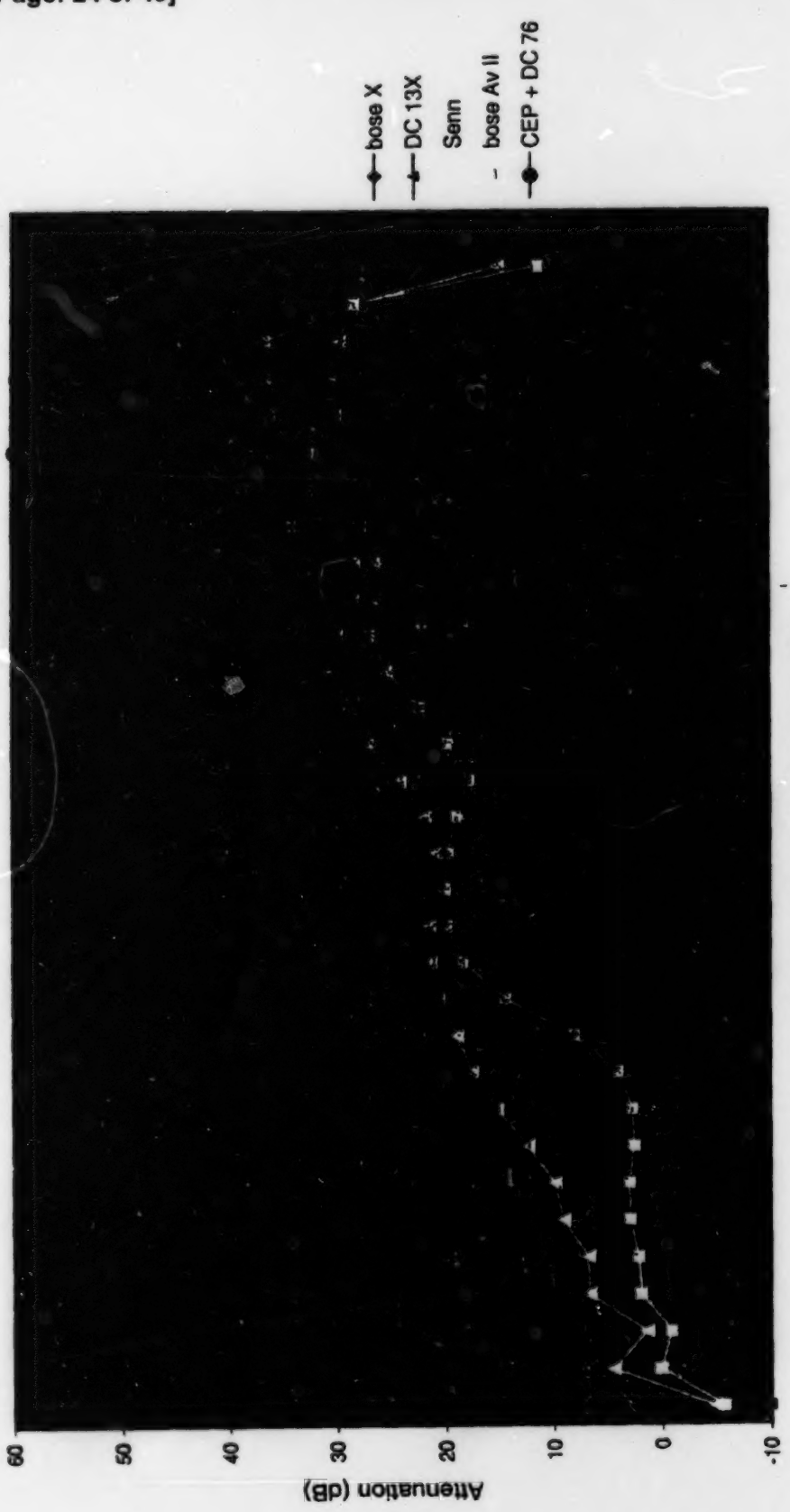

Figure 9: Attenuation of each Headset in 97dB Mauve Noise, ANR ON (average of all subjects)

Modified Rhyme Test

Differences seen in the results from the MRT between the male and female speaker were so small, they were probably not statistically significant. The results from both speakers were averaged to give figure 10 for ANR off and figure 11 for ANR on. Under both conditions, the lowest signal level is seen in the Sennheiser HMEC 222. With ANR off the Sennheiser HMEC 222 and the David Clark H10-76 have the lowest signal-to-noise ratios. The highest SNR was seen in the Bose AHX-04. With ANR on, the Sennheiser HMEC 222 and the CEP, worn in combination with the David Clark H10-76, displayed the lowest SNRs. Again, the Bose AHX-04 had the highest SNR. In all cases the noise level decreased when ANR was turned on, however the signal levels required for 60% speech intelligibility remained about the same for all headsets except the Sennheiser HMEC 222 and the Bose Aviation II where decreases of about 5 and 4 dB were seen, respectively.

Questionnaire Results

Results from the physical and experimental measures revealed that the Sennheiser HMEC 222 and the CEP in combination with the David Clark H10-76 performed the best. However, there are still other factors to consider: which is most cost effective and which is most comfortable. The questionnaires were scored on a scale from 1 – 5 across a continuum for answers. Questions were divided into categories of ANR, comfort and other so that specific totals could be compared. Questions left unanswered were assigned a neutral score of three. This was done so that totals would remain comparable. Tallies from the questionnaires in the comfort category ranked the leading two communications devices in the following order, the CEP in combination with the David Clark H10-76 at 54 points and the Sennheiser HMEC 222 at 53 points. With respect to ANR effectiveness, the Sennheiser HMEC 222 scored the lowest of all ANR headsets with a score of 212. However, comments provided by the subjects suggest that the Sennheiser HMEC 222 scored low in the ANR category due to a loud clicking that occurs when switching the ANR on and ANR off. This may not be an area of concern since the crew-members would not be switching between the conditions on a regular basis. Question 12 asked "how would you feel about wearing this headset for 8 – 10 hours at a time?" This is a relevant question since this is a typical duration of SAR missions. It also inquires about the headset in general giving the subject a chance to express an overall opinion. Subjects scored the CEP at 26, and the Sennheiser HMEC 222 at 24 in response to this question; total possible score was 35. Results from the questionnaire suggest that subjects found both of these devices comparable in both function and comfort. Please see Appendix C for the totalled scores of the questionnaires and the marking key.

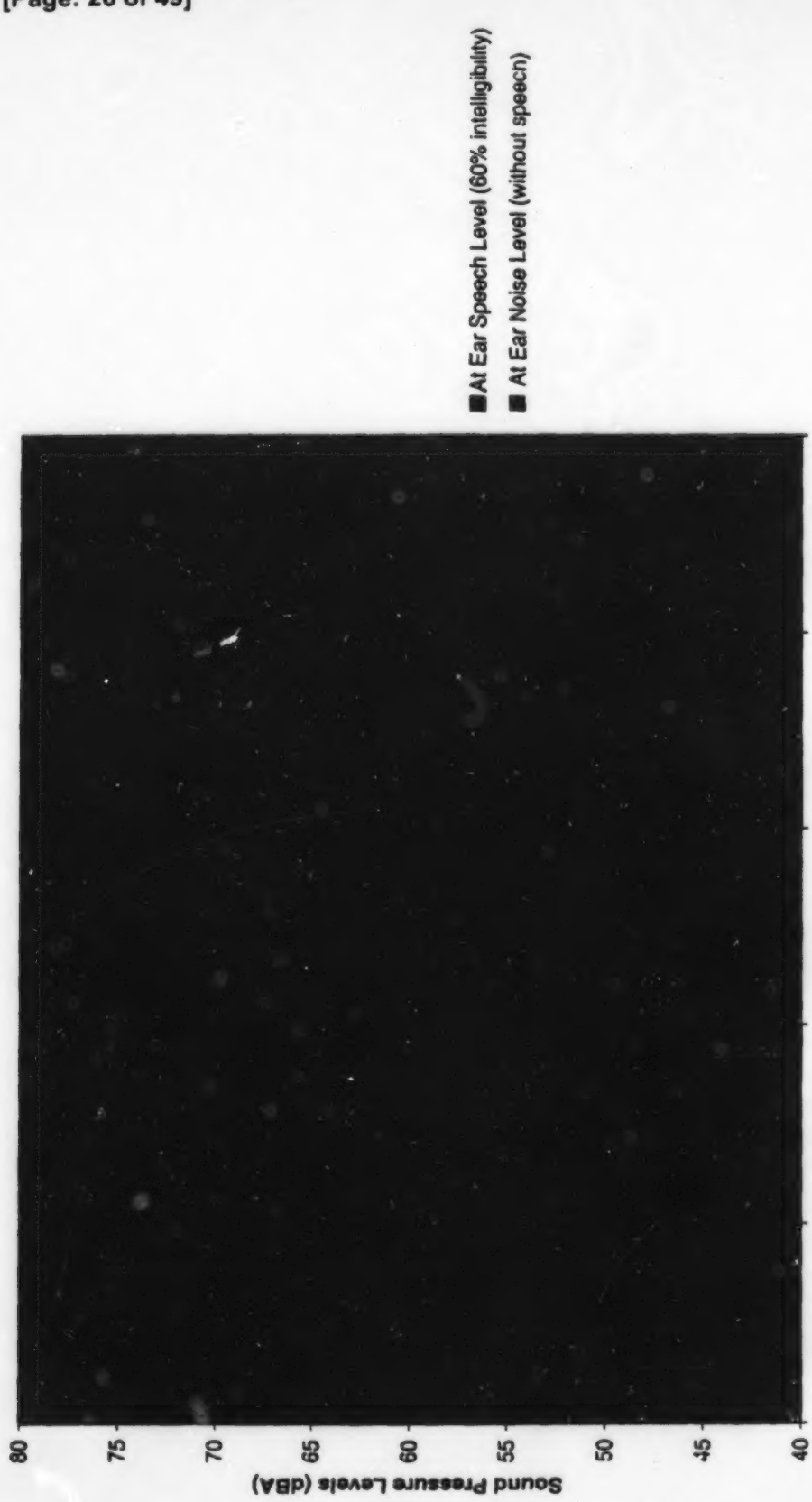

Figure 10: Signal (speech) and Noise Levels for each Communications Device, ANR OFF, Average of Male and Female Speakers

Figure 11: Signal (speech) and Noise Levels for each Communications Device, ANR ON, Average of Male and Female Speakers

Economical Efficiency

The most cost effective choice is the CEP; it is less than $100 US. Since it is worn in combination with the standard issue headset, the CEP is all that would need to be purchased. However, choosing the CEP creates new logistics problems for Hercules staff. Since the CEP is usually worn under a helmet, a new solution is needed to stow the wires in a convenient location that is also easy to connect to the ICS. A new interface between the CEP and the ICS would also have to be created, incorporating the David Clark H10-76 so that its microphone remains functional. The costs of these extra measures need to be accounted for. The Sennheiser HMEC 222 is priced at $1652 per headset and the Bose Aviation II at $1470 per headset. However, these are prices to purchase one unit, the price may decrease with a larger order.

Conclusion

The CEP worn in combination with the David Clark H10-76 and the Sennheiser HMEC 222 performed well under the conditions outlined in this study. Results from the MRT show the Sennheiser HMEC 222 to be the most effective communications device for speech intelligibility. This headset achieved the lowest noise levels in both conditions and the greatest and second greatest difference between signal and noise levels in the ANR on and off conditions, respectively. The CEP worn in combination with the David Clark H10-76 was ranked second in speech intelligibility, providing the second lowest signal level and difference between signal and noise levels.

In terms of attenuation, the Sennheiser HMEC 222 provided the greatest overall protection in both the active and passive (ANR on and off) conditions of all the headsets studied. The CEP worn in combination with the David Clark H10-76 provided competitive amounts of low frequency attenuation to those provided by the active ANR headsets. However, for reasons previously discussed, it is difficult to compare the attenuation of the CEP worn in combination with the David Clark H10-76 to the other headsets at higher frequencies.

Comments and scores from the survey suggest that subjects found these two devices, the Sennheiser HMEC 222, and the CEP worn in combination with the David Clark H10-76 similar in issues of comfort and function.

However, these two devices are not similar in terms of price. The CEP is far less expensive than the Sennheiser HMEC 222. Still, the cost of interfacing the CEP with the existing ICS systems and solving the problem of where to stow the necessary wires may raise the price of the CEP to a level more competitive with the Sennheiser HMEC 222.

In conclusion, the Sennheiser HMEC 222 functioned the most effectively in the experimental measures investigated in this study. The CEP worn in combination with the David Clark H10-76, placed a close second and should be less expensive to implement. Could purchasing the CEP rather than the Sennheiser HMEC 222 save enough funds to improve some other aspect of the CC 130 Hercules environment? Based on the results of this study, both of these devices should perform reliably and effectively in Hercules noise. Both provided greater attenuation and both produced lower SNRs to achieve the same level of speech intelligibility than the standard issue David Clark H10-76 worn alone. Therefore, both of these communications devices should offer improvement to the current acoustical situation in the CC 130 Hercules and hopefully work to preserve the hearing of the crew-members.

Recommendations

In order to better protect and preserve the hearing of the Hercules crew members, while at the same time increasing the effectiveness of speech communication, the standard issue David Clark H10-76 headset should either be replaced with the Sennheiser HMEC 222 or augmented with the Communications Earplug (CEP). Before a final decision is made, a number of things should occur. The Sennheiser company should be contacted to investigate what kind of pricing can be arranged for a group order. Inquiries should be made regarding the amount of time and money required to interface the CEP with the existing ICS and effectively stow the wires. There should also be some investigation as to whether the CEP affords a greater possibility of hearing damage when used improperly than the other headsets. Finally, both devices should be taken into flight allowing the SAR Hercules crew the opportunity to experience each device and express opinions as to which device is most effective in the operational environment.

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Appendix A - Photos of the CC 130 Hercules and the Communications Devices tested in this study.

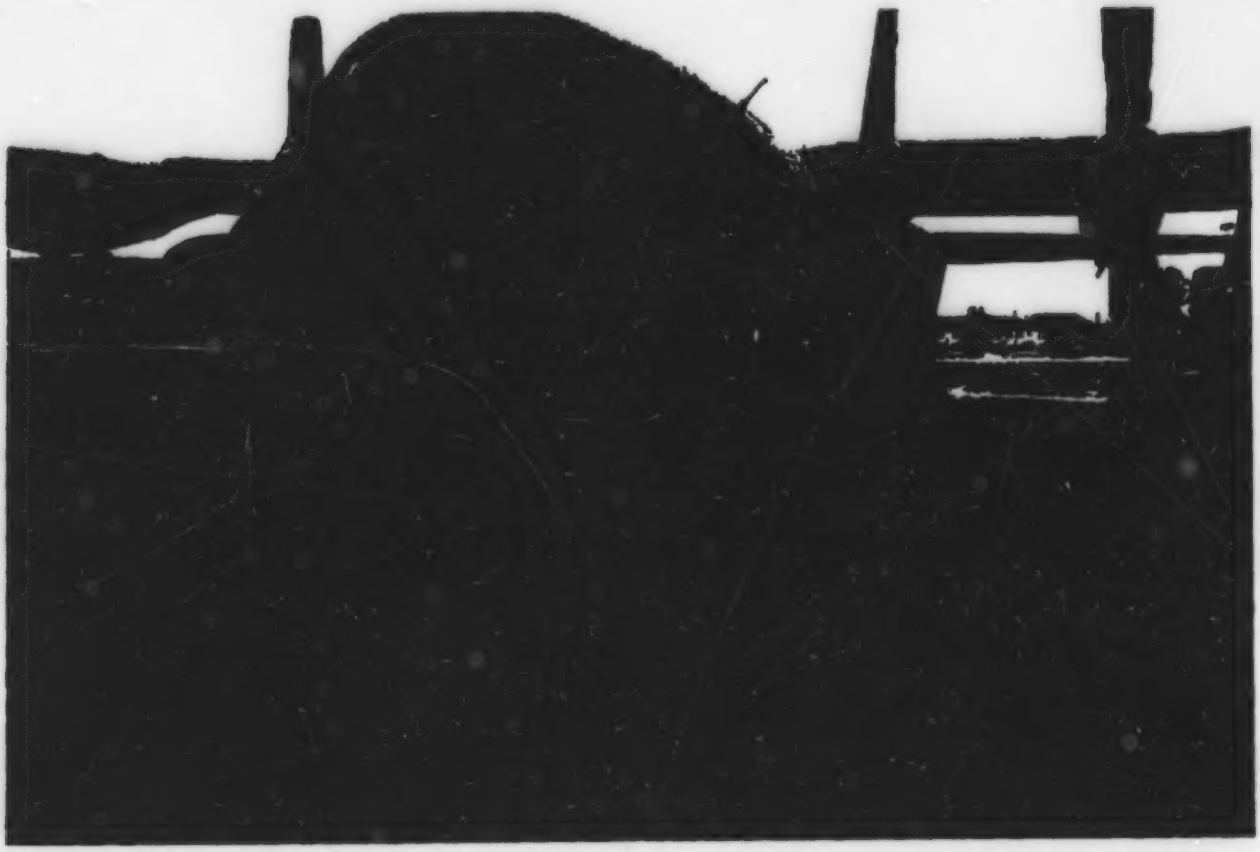

Figure A1: The Search and Rescue fixed wing aircraft, the CC 130 Hercules. In this photo the Hercules recieves post-flight maintenance at the Canadian Forces Base in Trenton, Ontario.

Appendix A - Photos of the CC 130 Hercules and the Communications Devices tested in this study.

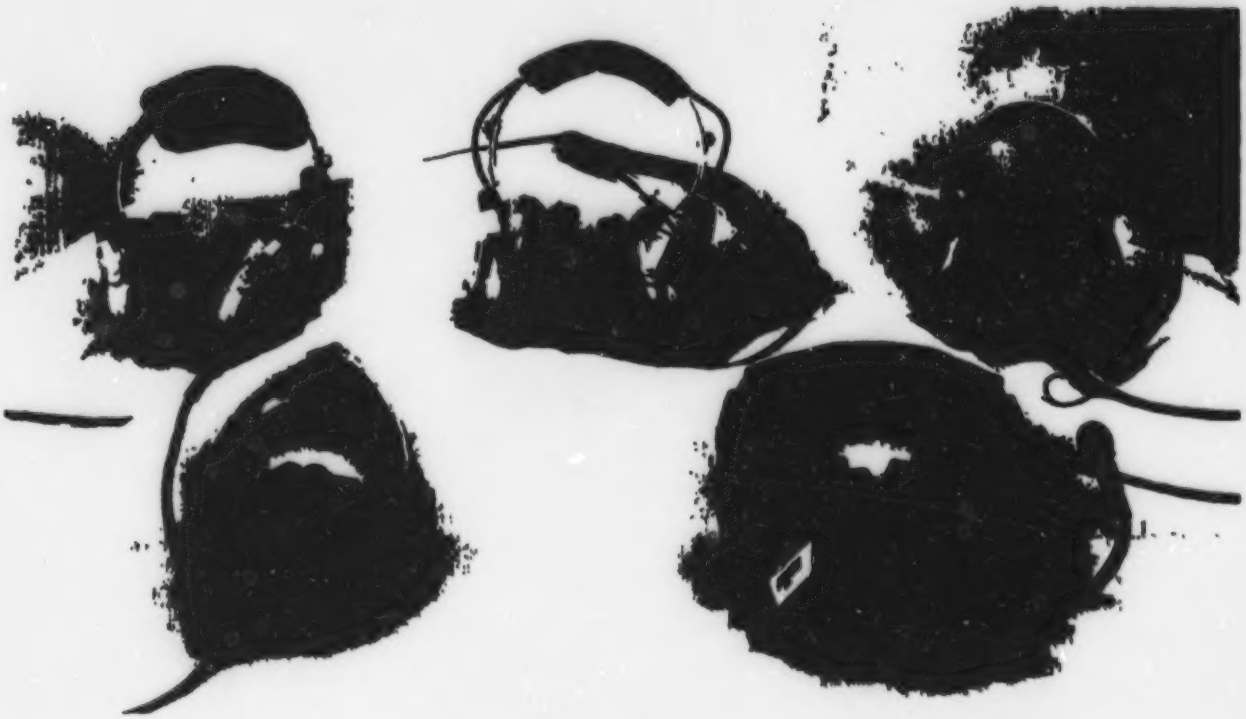

Figure A2: The five headsets studied in this project. In the back row from left to right: the David Clark H10-13X, the David Clark H10-76 (the standard issue communications headset) and the Sennheiser HMEC 222. In the front row from left to right: the Bose AHX-04 and the Bose Aviation II.

Figure A3: The Communications Earplug (CEP). The left side of the photo displays the interface between the transducer and the foam tip of a dissembled CEP. Two foam tips are displayed to show the difference between the standard and the slim sizes. The tips also come in a short size. The right side of the photograph shows an assembled CEP.

Appendix A - Photos of the CC 130 Hercules and the Communications Devices tested in this study.

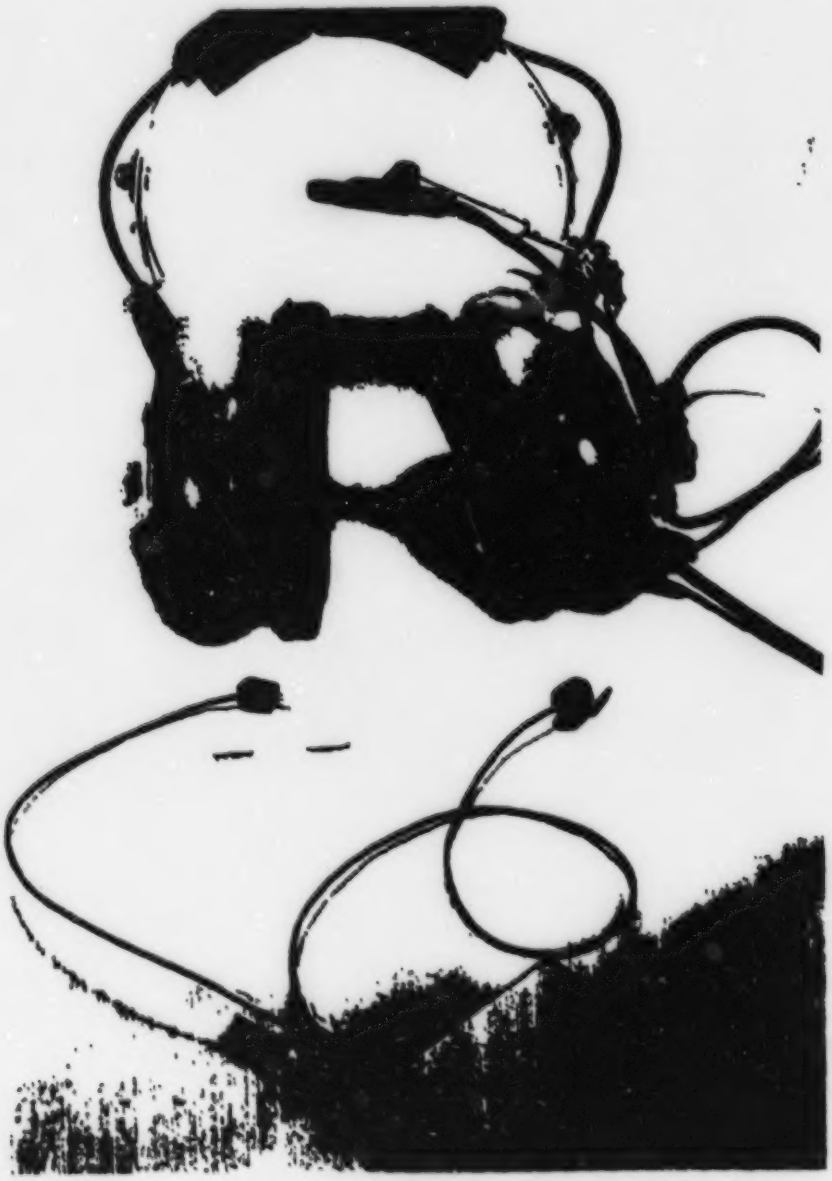

Figure A4: The Communications Earplug (CEP) is worn in combination with the standard issue David Clark H10-76. Special electronical interfacing is required to connect the audio of the intercommunications system to the CEP while maintaining a functioning microphone on the David Clark H10-76.

Appendix B - Supplementary Data Tables

Table B-1: At-ear noise levels for various Hercules crew-members during flight

	ICS off		ICS on	
position	left ear dBA	right ear dBA	left ear dBA	right ear dBA
co-pilot	81.9	77.3	85.6	84.9
flight engineer	76.3	76.6	82.3	85.4
load master	79.2	82.7	84.7	91.0

Table B-2: Starting signal-to-noise ratios (SNRs) for each communications device

	ANR off		ANR on	
device	male	female	male	female
Bose AHX-04	0	0	3	3
DC 13X	0	0	0	0
Senn HMEC 222	0	0	0	0
Bose Av II	2	0	1	2
DC 76	0	0	0	0
CEP + DC 76				

Appendix C - At-ear noise levels recorded under each headset in Hercules Noise

Sennheiser HMEC 222 ANR ON

Subject #	L. dBA	R. dBA
1	68.1	66.8
1	70.2	66.3
2	66.2	67.9
2	66.3	67.1
3	58.5	65.0
3	64.5	62.5
4	62.3	60.5
4	61.8	61.4
average	64.7	64.7

Sennheiser HMEC 222 ANR OFF

Subject #	L. dBA	R. dBA
1	73.2	72.1
1	73.2	71.0
2	68.8	73.2
2	70.6	72.0
3	69.5	72.2
3	69.0	66.0
4	65.6	66.3
4	65.3	66.2
average	69.4	69.9

6 Bose Aviation II ANR ON

Subject #	L. dBA	R. dBA
1	67.0	68.1
1	66.0	66.9
2	63.2	64.0
2	64.7	65.1
3	64.5	67.2
3	64.5	66.8
average	65.0	66.4

6 Bose Aviation II ANR OFF

Subject #	L. dBA	R. dBA
1	73.9	73.8
1	74.2	71.8
2	69.2	71.8
2	72.9	70.5
3	71.4	74.1
3	71.0	74.2
average	72.1	72.7

Bose AHX-04 ANR ON

Subject #	L. dBA	R. dBA
1	69.5	68.2
1	69.5	69.5
2	67.0	67.0
2	67.1	68.0
3	67.9	70.0
3	68.1	71.8
average	68.2	69.1

Bose AHX-04 ANR OFF

Subject #	L. dBA	R. dBA
1	74.0	75.9
1	76.0	74.5
2	73.0	75.1
2	73.4	75.2
3	74.5	77.1
3	74.9	77.1
average	74.3	75.8

Appendix C - At-ear noise levels recorded under each headset in Hercules Noise

David Clark H10-13X ANR ON

Subject #	L. dBA	R. dBA
1	81.5	78.0
1	81.0	78.0
2	72.2	74.4
2	72.9	75.0
3	71.0	73.0
3	74.5	72.1
4	68.8	72.0
4	71.2	72.2
average	74.1	74.3

David Clark H10-13X ANR OFF

Subject #	L. dBA	R. dBA
1	81.5	80.8
1	80.0	81.0
2	74.2	77.5
2	74.3	77.4
3	72.0	76.5
3	72.0	73.1
4	69.2	77.2
4	70.2	77.5
average	74.2	77.6

David Clark H10-76 (no ANR)

Subject #	L. dBA	R. dBA
1	83.0	79.4
1	83.8	80.5
2	71.1	73.1
2	74.1	73.9
3	71.5	70.0
3	70.1	70.8
4	70.1	76.0
4	70.0	75.2
average	74.2	74.9

Appendix D: Sample Questionnaires

Communications Questionnaire..... D-2 - D-5

Active Noise Reduction Questionnaire..... D-6 - D-9

Communications Ear Plug & David Clarke H10-76, David Clarke H10-76

Instructions for Communications Questionnaire

The following questions require a rating response and also provide space for comments. Please comment as frequently as you wish; your comments provide valuable feedback.

The questions will ask you to make a mark on a continuum between two extremes:
Ex.

Stable		Unstable

In this example, the closer to the 'STABLE' you perceive the system to be, the closer to the STABLE end of the continuum your mark should be placed. Alternatively, if you feel the system is 'UNSTABLE' then your mark should be placed nearer the UNSTABLE end of the continuum. The position of your response should indicate the strength of your opinion.

Thanks for your participation!

Question		Rating	
1. How would you rate this headset/headset plug combination for speech quality?	Good		Poor
Comments:			
2. How would you rate this headset/headset plug combination for noise attenuation?	Good		Poor
Comments:			

Communications Ear Plug & David Clarke H10-76, David Clarke H10-76

6. Did you experience any discomfort using this headset/headset plug combination?	Not at all		Entirely
Comments (please specify):			
6.b. How much of the discomfort was due to the ear microphones?	None		All
Comments:			
7. Was there any heat generated within the ear or ear cup by this headset/headset plug combination?	None at all		Thoroughly heated
Comments:			
8. a. Were there any adverse effects involving this headset/headset plug combination? If so, how frequent?	Never		Always
b. How severe were these adverse effects? If N/A, check ___	Insignificant		Serious
Comments:			

Communications Ear Plug & David Clarke H10-76, David Clarke H10-76

9. Was the headset/headset plug combination acoustically stable? (free from howls,clicks, etc.)	**Stable**		**Unstable**
Comments:			
10. Do you foresee any problems for this headset/headset plug combination within an operational environment?	**None at all**		**Entirely**
Comments (please specify):			
11. In general, how would you rate this headset/headset plug combination for use in an operational environment?	**Acceptable**		**Unacceptable**
Comments:			
12. How would you feel about wearing this headset/headset plug combination for 8-10 hours at a time?	**Pleased**		**Unacceptable**
Comments:			

Communications Ear Plug & David Clarke H10-76, David Clarke H10-76

13. What could be done to improve the comfort, convienience and/or effectiveness of this headset/headset plug combination?	Nothing		A lot
Please offer specific suggestions:			

Bose AHX-04, DC H10-13X, SENN HMEC 222, Bose AH-TS

Instructions for ANR Questionnaire

The following questions require a rating response and also provide space for comments. Please comment as frequently as you wish; your comments provide valuable feedback.

The questions will ask you to make a mark on a continuum between two extremes:
Ex.

Stable		Unstable

In this example, the closer to the 'STABLE' you perceive the system to be, the closer to the STABLE end of the continuum your mark should be placed. Alternatively, if you feel the system is 'UNSTABLE' then your mark should be placed nearer the UNSTABLE end of the continuum. The position of your response should indicate the strength of your opinion.

Thanks for your participation!

Question		Rating	
1. To what degree did ANR (ON) reduce unwanted noise levels compared to ANR OFF?	Complete Elimination		No Reduction
Comments:			
2. How did the ANR system rate for consistency of noise control while in use?	Consistent		Inconsistent
Comments:			
3. Did the ANR system fail?	Never		Completely
Comments:			

Bose AHX-04, DC H10-13X, SENN HMEC 222, Bose AH-TS

4. How would you rate the system for noise when switching between ON & OFF?	Acceptable		Unacceptable
Comments:			
5.a. How would you rate the headset for speech quality when ANR is OFF?	Good		Poor
b. How would you rate the headset for speech quality when ANR is ON?	Good		Poor
Comments:			
6. Did this headset cause any discomfort?	Not at all		Entirely
Comments (please specify):			
6.b. How much of the discomfort was due to the ear microphones?	None		All
Comments:			
7. Was there any heat generated within the ear cup by the ANR system?	None at all		Thoroughly heated
Comments.			

Bose AHX-04, DC H10-13X, SENN HMEC 222, Bose AH-TS

8. a. Were there any adverse effects involving the ANR system? If so, how frequent?	**Never**		**Always**
b. How severe were these adverse effects? If N/A, check ___	**Insignificant**		**Serious**
Comments:			
9. Was the system acoustically stable? (free from howls,clicks, etc.) a. with ANR off	**Stable**		**Unstable**
b. with ANR On	**Stable**		**Unstable**
Comments:			
10. Do you foresee any problems for this system within an operational environment?	**None at all**		**Entirely**
Comments (please specify):			
11. In general, how would you rate the ANR system for use in an operational environment?	**Acceptable**		**Unacceptable**
Comments:			

Bose AHX-04, DC H10-13X, SENN HMEC 222, Bose AH-TS

12. How would you feel about wearing this headset for 8-10 hours at a time?	Pleased		Unacceptable
Comments:			
13. What could be done to improve the comfort, convienience and/or effectiveness of this headset?	Nothing		A lot
Please offer specific suggestions:			

Appendix E - Questionnaire marking scheme and subject ratings for the leading two Communications Devices

Each spectrum was divided into 5 equal parts, and each part was assigned a number to be used as the score, 5 being the best and 1 being the worst. These 2 scores occured in the boxed portion of the spectrum on the questionnaire. Marks drawn by subjects were assigned the score corresponding to the portion of the continuum through which the line was drawn.

Question 6b was not tallied in either questionnaire. It was present simply to force subjects experiencing discomfort to think about its true source.
The total Comfort Score was tallied from questions 6a and 7 in both questionnaires.
The total ANR score was tallied from questions 1-4, 5b, 8 and 9b in the ANR questionnaire.

Communiations questionnaire-CEP & David Clark H10-76

	(random) Subject #							question total	
Question #	1	2	3	4	5	6	7		
1	4	4	5	4	5	5	5	32	
2	4	4	4	4	5	4	5	30	
6a	4	4	4	4	4	4	2	26	
6b									total comf 54
7	4	4	4	5	5	4	2	28	
8a	5	4	5	5	5	5	5	34	
8b	5	5	5	5	5	5	5	35	
9a	5	4	4	5	5	5	5	33	
10	4	4	4	3	5	5	3	28	
11	4	4	4	4	5	5	4	30	
12	4	4	4	3	4	4	3	28	"8-10hrs"
13	3	4	4	3	5	4	2	25	
total headset	46	45	47	45	53	50	41	327	

ANR questionnaire - Sennheiser HMEC 222

	(random) Subject #							question total	
Question #	1	2	3	4	5	6	7		
1	3	4	4	3	3	3	3	23	
2	3	3	5	4	2	4	5	26	
3	4	4	4	5	4	4	5	30	
4	2	2	5	3	3	3	2	20	
5a	2	5	4	3	4	3	4	25	
5b	2	5	4	3	4	4	4	26	
6a	4	4	4	3	3	5	4	27	
6b									total comf 53
7	2	3	4	4	3	5	5	26	total ANR 212
8a	4	4	5	4	5	4	3	29	
8b	4	5	5	4	5	5	3	31	
9a	2	5	4	4	4	4	5	28	
9b	2	5	4	4	4	4	4	27	
10	2	4	4	4	3	4	4	25	
11	2	4	5	4	4	4	4	27	
12	3	4	4	3	2	4	4	24	"8-10hrs"
13	3	3	4	3	3	5	4	25	
total headset	44	64	69	58	56	65	63	419	

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14. ABSTRACT

(U) The purpose of this project was to study ways of creating a better acoustical environment for the crew of the Search and Rescue (SAR) CC 130 Hercules aircraft. The ultimate goals were to improve communications and reduce noise dosage, thus preserving hearing. Several commercial products were tested to assess their effectiveness in accomplishing the two outlined goals. The products included various Active Noise Reduction (ANR) Headsets, the Communication Ear Plug (CEP), and the standard issue Communications Headset. The Microphone In Real Ear technique was used in real human subjects to assess the amount of attenuation provided by each headset when exposed to 97 dB of mauve noise. A Kunov Mannequin, a binaural acoustic test fixture, was used to assess the amount of attenuation offered by the CEP in the same environment. Real human subjects were also subjected to the Modified Rhyme test in combination with the Maximum Likelihood Procedure to determine the signal to noise ration required for each communications device to achieve a level of 60% speech intelligibility.
Out of all the communications devices tested, the Sennheiser HMEC 222 and the CEP, worn in combination with the David Clark H10-76 provided the greatest amounts of noise attenuation. In terms of speech intelligibility, the Sennheiser HMED 222 achieved the lowest signal to noise rations in both the active and passive modes. The Cep worn in combination with the David Clark H10-76 provided the second lowest signal to noise ration.
Based on performance in this study, the Sennheiser HMEC 222 is being recommended as the mot effective communications product for the Hercules environment. Competitive results were seen from the CEP which is a much more cost effective device. Therefore, SAR crews should have the opportunity to try both of these products during flight to assess issues of usability and comfort.

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